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Spatial assessment of the areas sensitive to degradation in the rural area of the municipality Čukarica

Natalija Momirović [a,*], Ratko Kadović [b], Veljko Perović [c], Miloš Marjanović [d], Aleksandar Baumgertel [b]

[a] Institute of Forestry, Kneza Višeslava 3, 11030 Belgrade, Serbia
[b] Faculty of Forestry, University of Belgrade, Kneza Višeslava 1, 11030 Belgrade, Serbia
[c] Institute for Biological Research "Siniša Stanković", University of Belgrade, Bulevar despota Stefana 142, 11060 Belgrade, Serbia
[d] Faculty of Mining and Geology, University of Belgrade, Đušina 7, 11000 Belgrade, Serbia

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ABSTRACT

In this paper, the assessment of the sensitivity of the soil in the rural area of Čukarica municipality to the processes of degradation is considered. Land areas, especially in the vicinity of large cities, are exposed to numerous processes of degradation: soil erosion, urban and industrial zone expansion at the expense of fertile agricultural soils, activation of landslides and a number of other significant ecological problems. Based on the characteristics of the research area, the MEDALUS (Mediterranean Desertification and Land Use) model was applied, and for the assessment of sensitivity to the processes of degradation the main quality indicators were considered: soil, climate, vegetation and management. For each of the analyzed quality indicators, parameter groups were identified. Each parameter is quantified according to the defined method by giving them a sensitivity coefficient between 1.0 and 2.0. ArcGIS 10.0 has been applied to analyze and prepare layers of quality maps. Subsequently, the geometric mean for all four quality indicators was used to generate the map of environmental sensitivity to degradation. The results obtained show that 41.54% of the study area is classified as critical; 22.34% of the surface as fragile; 8.47% of the areas are potentially endangered and 9.58% not threatened to degradation processes. The results have also shown that MEDALUS model is a functional tool for simulations which support sustainable land management in the areas prone to degradation.

1. Introduction

Land degradation is among the most serious environmental issues at global, regional, and local scales (Kosmas et al., 2014) which ultimately leads to a reduction of soil fertility (Fantechi, Peter, Balabanis, & Rubio, 1995). Caused by both natural and anthropogenic factors, according to Blum (1998), it occurs when the degradation processes significantly exceed nature's capacity of restoration. According to UNCCD (2015), 25% of the total land area is severely degraded or undergoing degradation. Land degradation and desertification affect over one billion people (Rubio & Recatala, 2006), and it's rapidly increasing. Moreover, according to D'Odorico, Carr, Laio, Ridolfi, and Vandoni (2013) almost two billion people are located over the drylands. Land degradation in arid, semi-arid, and dry sub-humid areas, resulting from various factors, climatic variation, and human activities is called desertification (UNEP, 1992). Combating drought, land degradation and desertification represents an international priority (UNCCD, 2008). What can accelerate land degradation and a desertification process is overexploitation of natural resources in extremely vulnerable areas. It is a major threat to humanity and the environment. (Vieira et al., 2015). In order to preserve land resources, as one of the nonrenewable resources, it is necessary to identify the causes which lead to degradation so as to be able to implement appropriate measures to prevent or slow down the process of land degradation.

MEDALUS model, developed within the eight year long international, interdisciplinary science project (Mediterranean Desertification and Land Use, 1991 – 1999) and financed by European Commission, is widely used as a successful tool for assessing and mapping area sensitivity to desertification/degradation because of its simplicity and flexibility. The methodology was validated and applied under Mediterranean conditions (Basso et al., 2000;

* Corresponding author.
E-mail address: natalijamomirovic@rocketmail.com (N. Momirović).

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Contador, Schnabel, Gutiérrez, & Fernández, 2009; Kosmas, Ferrara, Briasouli, & Imeson, 1999, Salvati & Bajocco, 2011) but later, the methodology was also applied over non - Mediterranean areas (Tavares et al., 2015; Vieira et al., 2015, Pravalie et al., 2017). For the detection of most endangered areas in terms of land degradation, first time in Serbia MEDALUS model was used to indicate the sensitivity to degradation processes of Deliblato sands (Kadović et al., 2016).

The main goal of this paper is to indicate the areas sensitive to degradation in the rural area of the municipality Čukarica using MEDALUS model, based on the available data about soil, climate, vegetation and management system.

The municipality of Čukarica is one of the 17 municipalities that constitute the city of Belgrade, the capital of Serbia. According to the latest landslide inventory from 2010 (http://mapa.urbel.com/beoinfo/), which includes the inner area of the General Plan of Belgrade and covers an area of 437 km^2 (1/3 of the total area of the city), over 30% of the territory is composed of active and suspended landslides (Lokin, Pavlović, & Trivić, 2010). On the territory of the municipality Čukarica, there is one of the biggest and the deepest landslide in Serbia which is, apart from its natural predisposition and hydraulic connection to the undercutting river Sava, triggered by the negative anthropogenic impact and an unplanned area urbanization process. The objective of the current study is to suggest an improved approach for assessing human pressure through inadequate urbanization of the unstable terrain, and for complementing the MEDALUS methodology. The results will be useful in providing basic information for the diagnosis of degradation in the region, mitigation and adaptation actions.

2. Material and methods

2.1. Study area

The Municipality of Čukarica (44°46' 59.99″ N, 20°24' 59.99″ E) belongs to the central city municipalities and it includes 8 residential areas such as Beograd-part, Velika Moštanica, Ostružnica, Rušanj, Sremčica, Umka, Pećani and Rucka. Its surface covers 157 km^2. A part of Čukarica outside the city includes the cadastral municipalities of Velika Moštanica, Ostružnica, Rušanj, Sremčica and Umka which cover 94.4 km^2, which is 60.13% of the whole municipality surface (Fig. 1).

According to the 2011 census, the municipality of Čukarica had the population of 181,231, while the part outside of the city had the population of 39,680 which is 21.89% of the total municipal population.

The municipality of Čukarica is located on the arterial road from Belgrade towards the west and south-west Serbia (M-19 and M-22 road). It is located on the right side of the river Sava, and it hosts one of the two main landslide types typical for Neogene formations in Serbia.

In the wider area around Belgrade, south to the river Sava and Dunabe (Antonović, Živanović, Bogdanović, Ćorović, & Trifunović, 1978), from the geological aspect, there are different substrates and layers. In river valleys there are a lot of alluvial and colluvial deposits, lake terrases are covered mainly by neogene sediments and in some places by loess, and on higher terrains there are limestones, sandstones, and in some cases even serpentine.

In these environmental conditions, different types of soil have been formed. According to the soil map (Antonović et al., 1978), the selected types of soil are divided into four groups: 1) fluvisol/regosol; 2) chernozem; 3) eutric cambisol and 4) gleysol/vertisol. The most common soils are eutric cambisol – 63.26%, fluvisol/regosol – 25.50%, gleysol/vertisol – 6.36% and chernozem – 4.88%.

Belgrade is located in the area of moderately continental climate with warm summers and cold winters. All four seasons are characterized by warm and cold periods. Cyclones coming from the west Mediterranean bring heavy rainfall. At the beginning of May, a cold and humid air is present. In May and June, local thunderstorms and heavy rainfall are very common, and the end of summer is characterized by short or sometimes longer dry season while at the end of September or the beginning of October late summer occurs. During a thirty-year period, from 1970 to 2000, average temperature was 12.0 °C, while average precipitation was 692,1 mm (Popović, 2007). Typical characteristics of Belgrade climate and the climate around the city of Belgrade is the south-east and east wind, Košava, which brings clear and dry weather. It is most common during autumn and winter, in the periods of 2–3 days. The average speed of Košava wind is 25–43 km h^{-1}, and in some cases it can achieve a speed of 130 km h^{-1}, thus it is considered one of the most significant means of purifying the air in Belgrade.

In the urban area such as Čukarica, but also in rural areas, the air is full of carbondioxide, methane, sulfurdioxide, nitrogen oxides and many other pollutants which have a negative impact on forest vegetation and agricultural areas as well as watercourses.

As for vegetation, in the analyzed area, as well as in wider territory south to the river Sava and Dunabe, there are mainly the following types of vegetation (Antonović et al., 1978): 1) wetland, most common next to the rivers Sava and Kolubara, less often near smaller tributaries; 2) meadow-pasture which covers the surface from river valleys to the hillsides; 3) forests which also cover the surface from the river valleys to the hilltops in this area.

According to CORINE Land Cover (2012), most of the study area is occupied by complex cultivation patterns with 22.26%, afterward broad-leaved forest 20.36%; non-irrigated arable land 18.67%; land principally occupied by agriculture, with significant areas of natural vegetation 16.26%; discontinuous urban fabric 15.92%; transitional woodland – shrub 1.96%; water courses 1.80%; pastures 1.49%; mixed forest 0.94%; industrial or commercial units 0.34% and mineral extraction sites 0.01%.

The urbanization processes are conspicuous across the whole territory of Čukarica municipality. Land urbanization is the changing of land use type by the conversion of rural areas into urban areas (Gerui, Yalin, Huajun, Sanmang, and Gejianping, 2017). The construction of urban areas and infrastructure in the process of land urbanization reduces the area of vegetation cover and cuts the slope which could trigger the reactivation of dormant landslides. According to Abolmasov, Milenkovic, Marjanovic, Djuric, and Jelisavac (2014) the urbanization of the area around the Umka landslide began in 1910, so that nowadays there are parts of the settlement built on stable ground, but also, significant part falls within the landslide area. It is unevenly urbanized, wherein about 500 dwelling and auxiliary buildings are present in the active sliding area (the situation might have been slightly changed since 2014). There is no sewage system, so the wastewaters are released either directly on the surface, or into septic tanks and old wells. This further influences soil saturation level, making the infiltration of the wastewaters down to bedrock (unweathered marls) one of the major causes of destabilization of the slope. Geometrically, the Umka landslide (Abolmasov et al., 2014) resemble a triangular fan, which is approximately 900 m long and 1450 m wide. The total surface area is approximately 1.3 km^2, while average slip surface depth equals 14 m. The total estimated volume is approximately 14 million m^3. The average slope inclination is 9°, apart from the main scarp and secondary scarp zones where it can reach as much as 25°. The toe of the landslide dips beneath the level of the river Sava. The existing M-19 road crosses through the landslide, and therefore becomes often subjected to large displacements, which require frequent repair work. Many buildings in Umka settlement, but especially those built over the landslide area have visible to

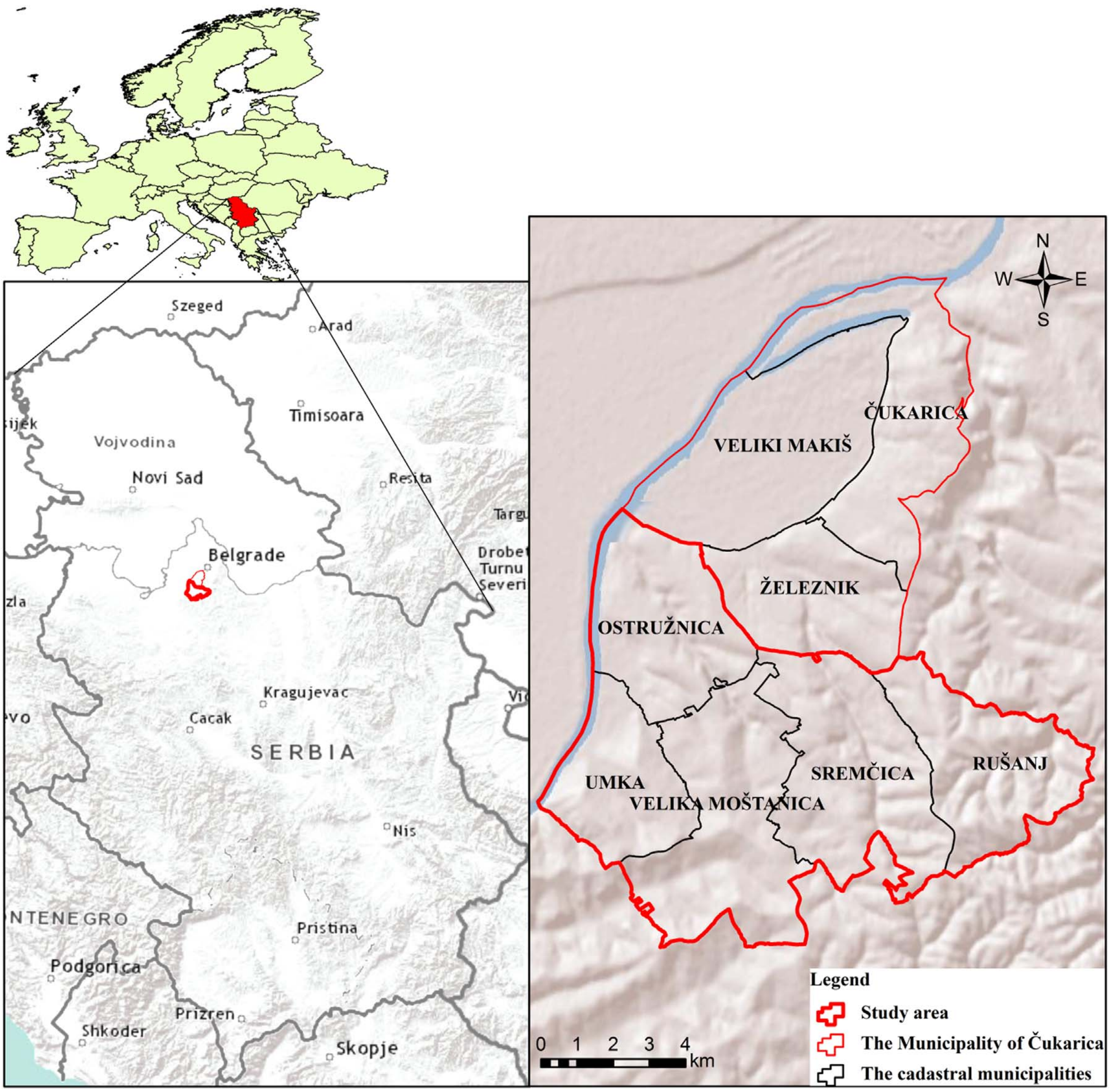

Fig. 1. Study area.

large deformations, while dozens of constructions have already suffered complete demolition. Apart from the landslides in the direction of Umka – Duboko – Barič, there is a significant landslide in the direction of Sremčica – Velika Moštanica, located on the valley sides of streams Sremački potok and Sibovački potok, characterized by spacious, unstable slopes with secondary landslides which endanger the soil and partly the residential area. Landslides in the rural area of the municipality Čukarica of are shown in Fig. 2 according to the stage of activity.

2.2. The MEDALUS method

The areas sensitive to land degradation are defined using the Environmental Sensitive Area Index (ESAI) which is first applied within the MEDALUS project (Kosmas et al., 1999). It is calculated using the geometric mean value of the four quality indexes: Soil Quality Index (SQI), Climate Quality Index (CQI), Vegatation Quality Index (VQI) which represent the environmental conditions and the Management Quality Index (MQI) that represents a pressure assessment on the environmental conditions as a result of anthropogenic activities. Quality indices are obtained by the geometric mean value of the appropriate parameters which have assigned values in the range of 1 (low sensitivity to land degradation) to 2 (high sensitivity to land degradation). The weight factors were assigned based on previous analyses of the literature (Kosmas et al., 2014; Pravalie, Savulescu, Patriche, Dumitrascu, & Bandoc, 2017; Salvati et al., 2013; Vieira et al., 2015; Tavares et al., 2015; Salvati & Bajocco, 2011) and according to the expert opinion (e.g. in the case of landslides, some similar studies and the authors of these studies have been interviewed, (Petrović et al., 2013, Marjanović, Đurić, Abolmasov, & Bogdanović, 2014)). For spatial distribution of certain parameters, one deterministic (inverse distance weighting (IDW)) and one geostatistical (cokriging (CK)) interpolation methods were used.

In this paper, depending on the availability of the input data and the research area characteristics, five parameters for soil quality assessment were used, while for the assessment of climate, vegetation and management quality only three parameters were used. The parameter which refers to susceptibility to landslides is a new one and it is incorporated into this kind of urbanistic studies for the first time. Landslide factor was introduced for a better assessment of management quality. It represents an inadequate management process through a great human pressure on the already unstable terrains without the implementation of the appropriate protection measures. The artificialized areas and water surface were not taken into account in the analysis of potentially

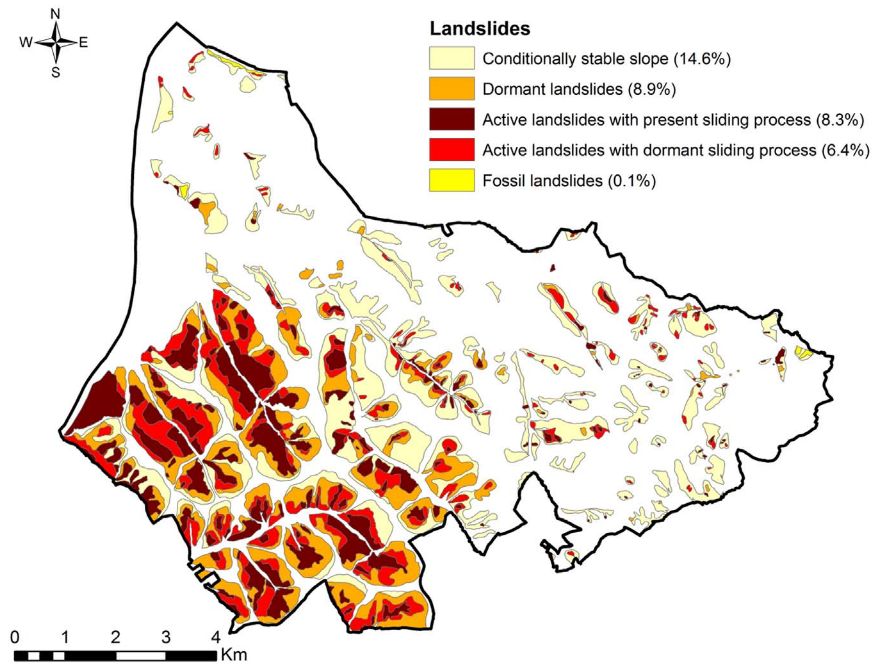

Fig. 2. The map of landslides according to the stage of activity for the rural area of the municipality Čukarica.

Table 1
Classes, description, source and assigned weighing indices for the parameters used for definition of soil quality.

Source	Parameters	Description	Susceptibility class	Weight index
Basic geological map SFRJ 1:100 000	**Parent material** (Kosmas et al., 1999; Vieira et al., 2015, adjusted according to the local geological characteristics by Marjanović et al. 2014)	Dacito-andesite and latite	Low	1.05
		Layered and massive limestone	Medium	1.55
		Flysch; Sandstone, marl and shale; Conglomerate, sandstone and shales;		1.60
		Limestone, clay and sandy clay; Shale and marl		1.65
		Clayey marl, shale, sand and gravel; Allevrite and marl; Marl, shale and allevrite		1.70
		Loess-like clay and sand	High	1.75
		Sand and clayey sand; Sand and gravel with Corbicula fluminalis; Sand and allevrite;		1.80
		Grey-bluish marly and ferrous clay; Delluvial-proluvial sediments		2.00
ASTER GDEM V2	**Slope (%)** (Kosmas et al., 2014)	< 2 Nearly level	Low	1.0
		2–6 Gentling sloping		1.2
		6–12 Moderately sloping	Medium	1.4
		12–18 Strongly sloping		1.6
		18–25 Moderately steep	High	1.7
		25–35 Steep		1.8
		35–60 Very steep		1.9
		> 60 Very steep		2.0
Database of the Institute for Soil Science from Belgrade; Antonović et al. (1978)	**Soil depth (cm)** (Kosmas et al., 2014)	< 15 Very shallow	Very High	2.0
		15–30 Shallow	High	1.8
		30–60 Moderately shallow	Medium	1.6
		60–100 Moderately deep		1.4
		100–150 Deep	Low	1.2
		> 150 Very deep	Very low	1.0
	Organic matter content (%) (Kosmas et al., 2014)	> 6.0	High	1.0
		2.1–6.0	Medium	1.3
		2.0–1.1	Low	1.6
		< 1.0	Very low	2.0
	Soil texture (class) (Kosmas et al., 1999)	L, SCL, SL, LS,CL Good	Very Low	1.0
		SC, SiL, SiCL Moderate	Low	1.2
		Si, C, SiC Poor	Medium	1.6
		S Very Poor	High	2.0

Table 2
Classes, description, source and assigned weighing indices for the parameters used for definition of climate quality.

Source	Parameters	Description	Susceptibility class	Weight index
The Republic Hydrometeorological Service of Serbia's Meteorological annuals	**Aridity index** (mm/mm)	< 0.05 Hyper-arid zone	Very high	2
		0.05–0.2 Arid	High	1.8
		0.2–0.5 Semiarid	Medium	1.6
		0.5–0.65 Dry subhumid		1.4
		0.65–1 Subhumid	Low	1.2
		> **1 Humid**	**Very low**	**1**
	Erosivity (Modified Fournier index) (Tavares et al., 2015)	0–60 Very low	Very low	1
		60–90 **Low**	**Low**	**1.2**
		90–120 Moderate	Medium	1.5
		120–160 Severe	High	1.8
		> 160 Very severe	Very high	2
ASTER GDEM V2	**Aspect** (Pravalie et al., 2017)	N, NW, NE,W, flat areas	Low	1
		S, SW, SE,E	High	2

Table 3
Classes, description, source and assigned weighing indices for the parameters used for definition of vegetation quality.

Source	Parameters	Description	Susceptibility class	Weight index
CLC, 2012	**Drought resistance** (Pravalie et al., 2017)	Broad-leaved forest; mixed forest; transitional woodland – shrub	Very low	1.0
		Land principally occupied by agriculture, with significant areas of natural vegetation	Medium	1.4
		Pastures; complex cultivation patterns	High	1.7
		Non - irrigated arable land	Very High	2.0
	Erosion protection (Pravalie et al., 2017)	Broad-leaved forest; mixed forest	Very low	1.0
		Pastures; land principally occupied by agriculture, with significant areas of natural vegetation; transitional woodland – shrub	Low	1.3
		Complex cultivation patterns	Medium	1.6
		Non - irrigated arable land	High	2.0
	Vegetation cover (Pravalie et al., 2017)	Pastures; land principally occupied by agriculture, with significant areas of natural vegetation; broad-leaved forest; mixed forest; transitional woodland – shrub	Low	1
		Complex cultivation patterns	Medium	1.8
		Non - irrigated arable land	High	2

Table 4
Classes, description, source and assigned weighing indices for the parameters used for definition of management quality.

Source	Parameters	Description	Susceptibility class	Weight index
CLC, 2012	**Agricultural intensity** (Salvati & Bajocco, 2011; Pravalie et al., 2017)	Land principally occupied by agriculture, with significant areas of natural vegetation; broad-leaved forest; mixed forest; transitional woodland – shrub	Low	1
		Non - irrigated arable land; pastures	Moderate	1.5
		Complex cultivation patterns	High	2
http://mapa.urbel.com/beoinfo/	**Landslides** (expert opinion, (Marjanovic, personal communication))	Stable terrain	Very low	1
		Conditionally stable slope	Low	1.4
		Fossil landslides	Medium	1.5
		Dormant landslides		1.6
		Active landslides with dormant sliding process	High	1.8
		Active landslides with present sliding process	Very high	2
Statistical Office of the Republic of Serbia	**Population density** (people/km^{-2}) (Kosmas et al., 2014)	< 50	Low	1
		50–100	Medium	1.3
		100–300	High	1.7
		> 300	Very high	2

degraded areas. Further in the text, those surfaces are addressed to as mask areas, selested on the basis of the CORINE database (2012), and they consist of discontinuous urban fabric, industrial or commercial units, mineral extraction sites and water courses.

Spatial data analysis and mapping the areas sensitive to land degradation was conducted in Geographical Information System (GIS) environment. Sources of information necessary for obtaining certain parameters are shown in the Tables 1–4.

2.2.1. Soil quality

For the soil quality estimation one topographic (slope) and four soil characteristics (parent material, soil depth, soil texture and organic matter of surface layer) were selected.

In order to conduct soil quality assessment for the input data, ASTER DEM was used, a database of the Institute for Soil Science from Belgrade, as well as data taken from Antonović et al. (1978).

Classes and assigned weighting indices for selected parameters for soil quality assessment are given in Table 1, according to: Kosmas et al. (1999), Kosmas et al. (2014); Vieira et al. (2015). The geological layer is adjusted according to the local geological conditions, based on some earlier works and experts opinions (verbal consultations with about ten experts) for this particular research, by the corresponding group of authors (Petrović et al. 2013, Marjanović et al., 2014). It is generally suggested to treat the solid non-weathered rock as low susceptibility class, sedimentary clastic rocks as intermediate, and plastic-deformable and non-cohesive

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rock as highly susceptible (Table 1). Soil quality index (SQI) was calculated as the product of the above-mentioned parameters using the following equation:

$$\boldsymbol{SQI} = (\textbf{Parent material} * \textbf{Slope} * \textbf{Soil depth} * \textbf{Organic matter} * \textbf{Soil texture})^{1/5} \tag{1}$$

2.2.2. Climate quality

Climate characteristics were studied based on the data on air temperatures and precipitation for the weather station Belgrade – Automatic weather station Košutnjak (N 44°46', E 20°25',H: 203 m) for the period between 1990 and 2016. The data were obtained from the Republic Hydrometeorological Service of Serbia's Meteorological annuals.

Climate quality was assessed using Aridity Index (which influences water availability to the plants, (Kosmas et al., 1999)), Modified Fournier Index (which estimates the rainfall aggressiveness) and aspect (which affects microclimatic conditions and soil erosion rate (Salvati et al., 2013).

Aridity Index (UNEP, 1992) obtained using the formula:

$$AI = P/PET \tag{2}$$

In the Eq. (2) P represents a total amount of precipitation annually, while (PET) represents a potential evapotranspiration obtained using the Thornthwaite method – a (1948). Modified Fournier Index (MFI) (Arnoldus, 1980) was taken for assessing erosivity and calculated according to the equation:

$$MFI = \sum_{i=1}^{12} P_i^2/P \tag{3}$$

According to Szilagyi, Irimus, Toganel, and Szilagyi (2016), MFI holds a bigger relevance than Fournier Index proposed by Fournier (1960) because it estimates the rainfall aggressiveness considering the rainfall quantity registered in each month (pi) and the annual rainfall quantity (P) (Eq. (3)). Aspect was obtained from the digital elevation model.

Classes and assigned weighting indices for selected parameters for climate quality assessment are shown in Table 2, according to: Tavares et al. (2015); Pravalie et al. (2017). Climate quality index (CQI) was calculated according to the algorithm:

$$\boldsymbol{CQI} = (\boldsymbol{Aridity\ Index} * \boldsymbol{Erosivity} * \boldsymbol{Aspect})^{1/3} \tag{4}$$

2.2.3. Vegetation quality

The major factors affecting vegetation quality in the studied area are erosion protection (the protection that plants provide against soil erosion), vegetation drought resistance (that indirectly indicates the capability of an ecosystem to adapt to climate aridity and severe drought episodes (Salvati et al., 2013)), and plant cover (essential in reducing runoff and sediment loss). To achieve the definition of erosion protection, drought resistance and vegetation cover parameters, different vegetation classes were derived and scored from the CORINE Land Cover map (CLC, 2012)

Classes and weighting indices of parameters used for assessing vegetation quality are given in Table 3 (Pravalie et al., 2017). Vegetation quality index (VQI) was calculated using the formula:

$$\boldsymbol{VQI} = (\boldsymbol{Vegetation\ cover} * \boldsymbol{Erosion\ protection} * \boldsymbol{Drought\ resistance})^{1/3} \tag{5}$$

2.2.4. Management quality

The management quality was analyzed from the aspects which are significant in terms of quality management and the level of anthropogenic effect to stress production (Kadović et al., 2016). The three considered layers were agricultural intensity, population density, and landslides. The former two can be considered as standard inputs, while introducing a landslide factor is somewhat innovative. Therefore, some further details will be addressed.

Landslide activity is used as a primary criterion for the assessment of landslide hazard/susceptibility. The activity stage was estimated during the field surveys that followed a massive landsliding event in Serbia in 2014. Čukarica territory was no exception of the massive scales of floods and landslides, and therefore was included in both preliminary survey for quick damage estimation, as well as in the subsequent detailed mapping. In both cases, the field survey included a standardized inventory sheet, which required filling-in of the activity estimation, among other properties visible in situ. The guideline recommendation for corroborating the activity stage included considering freshness of the tension cracks and scarps, deformations on the constructions, devastated vegetation, as well as testimonies of affected locals and technical reports of local authority administration. An example of such data collection, but for a different territory is given in Marjanović, Vulović, Đurić, and Božanić (2016).

According to their activity, landslides in the area of interest are divided into (Lokin & Abolmasov, 2008):

1. Active landslides with two sub-categories
   - o Active with an acute/present sliding process
   - o Active with a temporarily suspended/dormant sliding process (between two phases of activity)
2. Dormant landslides – stabilized by the natural erosional processes (reaching topographic slope equilibrium) and reactivation is not expected
3. Fossil landslides – landslides overlaid with younger sediments so reactivation process is not expected, unless the human activity disturbs the entire cover and re-exposes the landslide that is underneath
4. Conditionally stable slope–slopes with no sliding, but with inclination and rock mass properties that suggest the activation of the slope, especially in the extreme environmental or anthropologic conditions.
5. Stable terrain

Scoring of these classes for their subsequent introduction into Management Quality Index was completed by the probability criterion. Probabilities of landslide reactivation are semi-linearly transformed into predefined 1–2 scoring scale. For instance, by definition active landslides are re-occurring within one-year cycle, so the according probability equals 1, whereas the total score is 1 + 1. Active landslides with temporarily suspended process are re-occurring within two years so their probability is 0.5–1, their score is 1 + (0.5–1), where 1 + 0.8 is considered rather appropriate than e.g., 1 + 0.5 in order to account for possible extreme weather conditions. Fossil and dormant landslides are primarily triggered by human intervention. Therefore, it is difficult to empirically involve them in the probability context, but a score range 1.5–1.6 seems appropriate as it is higher than stable but lower than naturally susceptible classes. The lowest probability is assigned to the stable classes, wherein some apparently and currently stable slopes can become unstable in extreme conditions. In the light of the recent weather extremes in Serbia, assigning the score of 1.4 is on the safe side.

Classes and weighting indices of parameters used for assessing Management Quality Index are given in Table 4 according to: Salvati and Bajocco (2011); Pravalie et al. (2017); Kosmas et al. (2014). The management quality index (MQI) is assessed as the product of the above-mentioned layers related to sensitivity to degradation as follows:

$$\boldsymbol{MQI} = (\boldsymbol{Agricultural\ intensity} * \boldsymbol{Landslides} * \boldsymbol{Population\ density})^{1/3} \quad (6)$$

2.2.5. Environmentally Sensitive Areas (ESAs)

Land sensitivity to degradation was defined as the final step in environment quality (soil quality, climate quality and vegetation quality) and management quality assessment based on original methodology (Kosmas et al., 1999) classifying the area into four main classes (not affected (N), potentially affected (P), fragile (F) and critical (C)) and 8 sub-classes (N, P, F1, F2, F3; C1, C2, C3). ESAI (Environmentally Sensitive Areas Index) was obtained from the geometric average of four above mentioned layers using the algorithm:

$$\boldsymbol{ESAI} = (\boldsymbol{CQI}*\boldsymbol{SQI}*\boldsymbol{VQI}*\boldsymbol{MQI})^{1/4} \quad (7)$$

2.3. Statistical analyses

A mutual interconnection between the following factors (SQI, CQI, VQI and MQI) and their individual correlation to ESAI has been analyzed in ArcGIS by using Band Collection Statistics tool. Correlation ranges from +1 to -1 where a positive correlation indicates a direct relationship between two layers while a negative correlation means that one variable changes inversely to the other. Two layers are independent of one another when a correlation coefficient value is zero.

3. Results and discussion

This paper represents the first effort to identify the areas that are most susceptible to degradation in an area outside the city of Čukarica, through a system that enables integrated analysis of the factors that provide the best explanation of the degradation processes. Analyses from 14 parameters stress that areas are potentially susceptible to degradation due inadequate soil management which is a key factor for the adaptation and mitigation of land degradation.

Quality indicators (SQI, CQI, VQI, MQI) are shown in the Table 5, where the land area in percentage and km^2 of each quality class and its score range are given. Spatial distribution of each quality indicator is shown in Fig. 3.

Table 5
The land area in percentage and km^2 covered by each quality class of the four quality indicators, according to the classification scheme suggested by Kosmas et al. (1999) and Pravalie et al. (2017).

Indicator	Class	Quality description	Score range	Total area (km^2)	Total area (%)
SQI (Kosmas et al., 1999)	1	High quality	< 1.13	0.28	0.29
	2	Moderate quality	1.13–1.45	68.53	72.62
	3	Low quality	> 1.46	8.52	9.03
CQI (Kosmas et al., 1999)	1	High quality	< 1.15	44.15	46.78
	2	Moderate quality	1.15–1.81	33.17	35.15
	3	Low quality	> 1.81	–	–
VQI (Pravalie et al., 2017)	1	High quality	< 1.13	21.92	23.23
	2	Moderate quality	1.13–1.38	16.75	17.75
	3	Low quality	> 1.38	38.65	40.96
MQI (Kosmas et al., 1999)	1	High quality	1–1.25	12.87	13.63
	2	Moderate quality	1.26–1.50	33.18	35.15
	3	Low quality	> 1.51	31.28	33.15
Mask areas				17.05	18.06

In terms of SQI, the obtained data revealed that the areas characterized by high soil quality occupied about 0.29% of the total area (0.28 km^2), the moderate soil quality index occupied an area of about 72.62% of the investigated area (68.53 km^2), while 9.03% of the total area (8.52 km^2) was characterized by low soil quality index.

In terms of CQI, 46.78% of the study area (44.15 km^2) is characterized by high climate quality, while the moderate climate quality occupies an area of 33.17 km^2 representing 35.15% of the total area.

In respect of VQI, 40.96% appears with low vegetation quality, 17.75% with moderate vegetation quality, and 23.23% with high quality. The areas of low vegetation quality are mainly complex cultivation patterns and non - irrigated arable land.

According to the obtained data, 33.15% of the study area (31.28 km^2) is suffering from mismanagement of land resources and inappropriate land use systems. The areas of moderate management quality represent about 35.15% of the total area (33.18 km^2) while 13.63% of the total area (12.87 km^2) is characterized by a high quality index.

The map of Environmentally Sensitive Areas to degradation for the rural area of the municipality Čukarica is presented in Fig. 4. It is clearly showed that a large part of the study area (41.54%) falls into the critical classes (with a major presence of C2 class); furthermore, 22.34% of the study area is classified as Fragile (with a major presence of F2 class), 8.47% as Potential and 9.58% Not Threatened (Table 6).

Correlation coefficients between Quality indices (SQI, CQI, VQI, MQI) and between each Quality index and ESAI are shown in Table 7.

The presented results showed several areas with high susceptibility to land degradation processes (Fig. 4). Sensitivity scores provide a reliable estimation of different levels of sensitivity occurring in a specific area.

The critical areas (C1, C2 and C3) are mainly located closer to urban zones, because of a high population density pressure which induce very low vegetation cover mostly occupied with parcels of arable crops. The results also showed that degradation processes in this area are increasing due to inadequate soil management and urbanization, i.e., the human activities are the dominant factor for degradation expansion.

The first application of proposed methodology (Kosmas et al., 1999) for different areas sensitive to desertification was performed for three characteristic Mediterranean areas: the island of Lesvos in Greece (Kosmas et al., 1999), the Agri basin in Italy (Basso et al., 2000) and the Alentejo region in Portugal (Roxo, Mourao, Rodrigues, & Casimiro, 1999). Eight classes of land sensitivity were established according to the obtained ESAI scores recommended by Kosmas et al. (1999).

After establishing that methodology, there are more examples of mapping sensitivity to land degradation both in the Mediterranean and non-Mediterranean basins: in Spain (Contador et al., 2009), in Italy (Basso et al., 2000; Salvati & Bajocco, 2011; Salvati et al., 2013), in Egypt (Mohamed, 2013), in Cabo Verde (Tavares et al., 2015), in Brasil (Vieira et al., 2015), in Romania (Pravalie et al., 2017), in Greece (Karamesouti, Panagos, & Kosmas, 2018) in Serbia (Kadović et al., 2016), etc. The final maps of sensitivity were obtained by partitioning the ESAI into eight classes of sensitivity values, arranged according to their degree of sensitivity.

With MEDALUS method we can estimate additional variables that characterize specific habitat conditions, which depend on local conditions. That procedure refers to the process of classification by interpreting different layers of information.

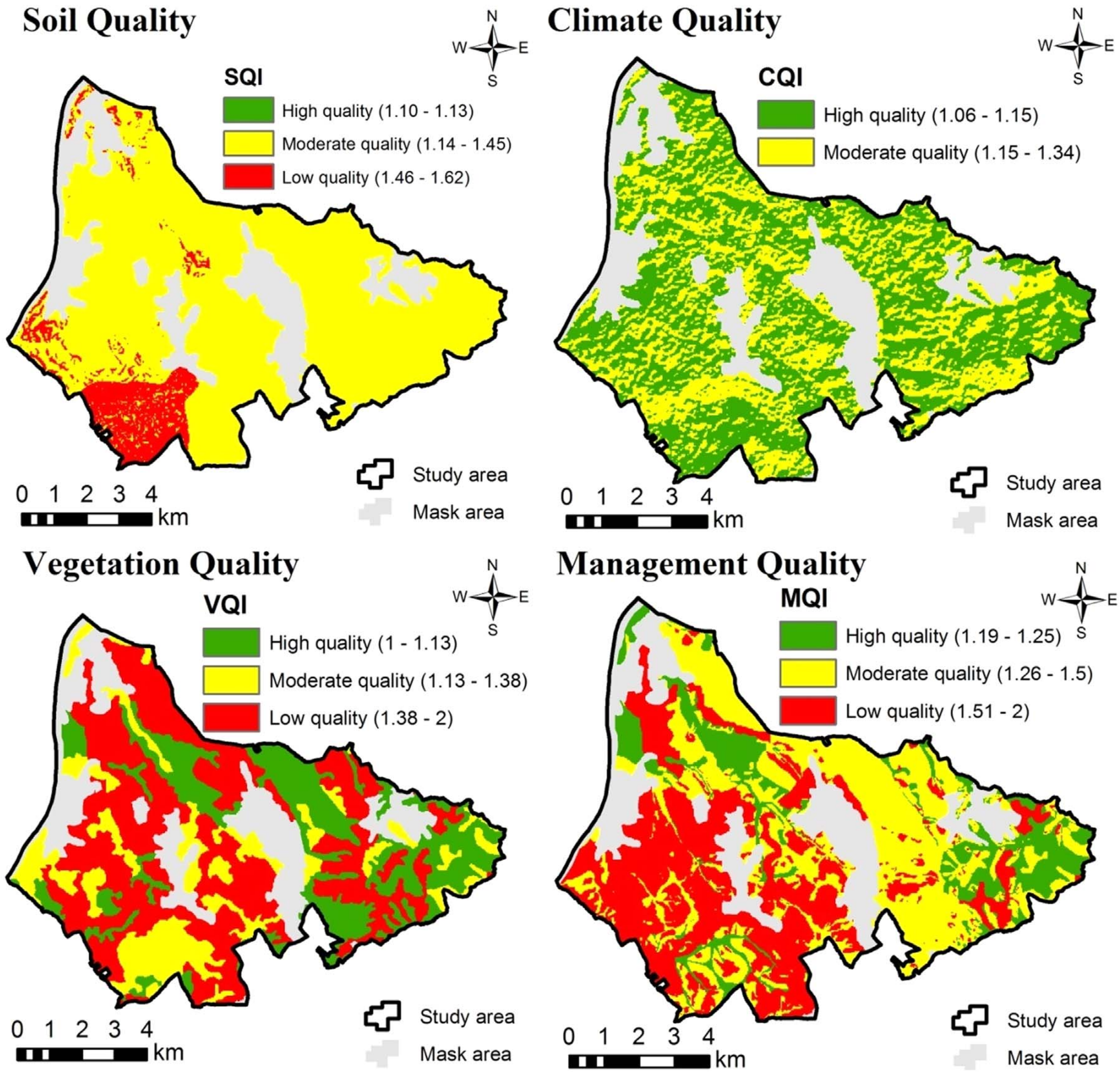

Fig. 3. Spatial distribution of soil quality (SQI), climate quality (CQI), vegetation quality (VQI) and management quality indicator (MQI).

Summarizing the values of different attributes within a limited number of classes (Salvati & Zitti, 2009) we simplify classifications data. Presentation of data calls for uniform classifications with data organized into reference systems or when different types of ecosystems are compared (Salvati et al., 2013). Here, in the case of the rural part of Čukarica municipality, the changes in the index of vegetation quality due to not applied management policy are well-expressed through correlation coefficient (0.87 VQI and 0.75 MQI). Simulation technique, applied with the available information and supported by the collected data, can be used for the study of specific degradation processes, primarily landslides which in this case study covered 38.4% of the area with a different stage of activity.

The MEDALUS model is a useful tool for simulations that support sustainable management of land in the areas sensitive to degradation processes like the rural part of Čukarica municipality is, which was also confirmed with obtained results. The land use changes, soil deterioration and climate variations should be continuously monitored to inform sustainable land management strategies.

4. Conclusion

The result of this study showed that through the integration of MEDALUS model it was possible to assess a land degradation risk. The model can be easily modified on the basis of local conditions and data availability. The landslides were integrated into the methodology for better estimation of the management quality index.

Based on the developed ESAs map for the rural area of the municipality Čukarica it can be concluded that the major part of this territory is classified as critical 41.5%, 22.3% as fragile, 8.5% as potential and only 9.6% of the area is not threatened by degradation (Mask area occupies 18.1% of the territory). Considering the high percentages of the low quality classes of the all four indicators it can be concluded that vegetation quality and management quality have the highest importance for the lands sensitivity to degradation which is also clearly expressed through correlation coefficients (0.87 VQI and 0.75 MQI). The study area is highly susceptible to land degradation due to inadequate soil management associated with intensive agricultural land expansion. Poor or non-existent land-use policies allow building and other constructions to take place on lands that might have been deemed too hazardous in the past but now are the only areas that remain for a growing population.

The environmentally sensitive areas map proved to be a good source of information to help local authorities to mitigate degradation processes in the municipality of Čukarica. The obtained results can be used in the future for sustainable land management. This study indicates that there are indicators for each cause of land degradation related to human activities which can be changed by

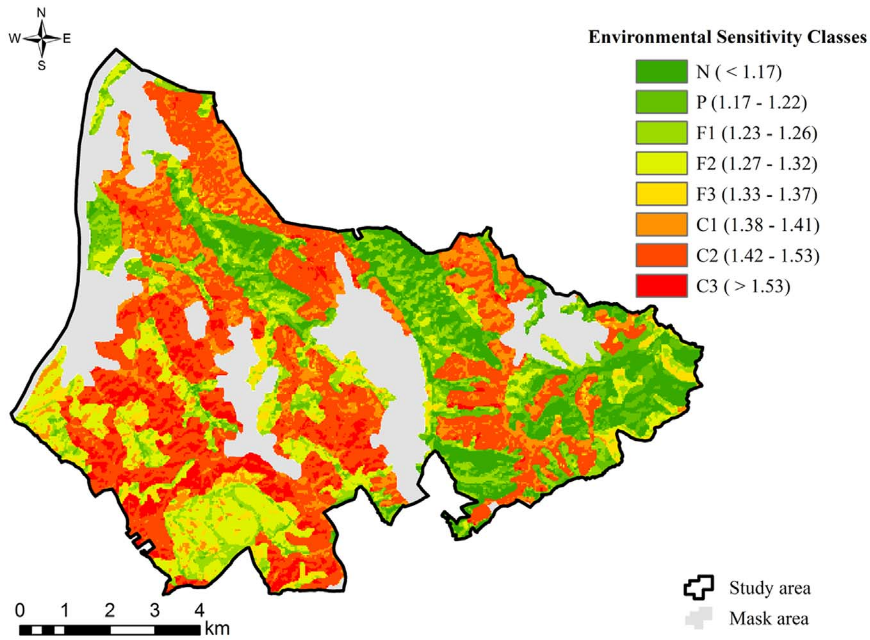

Fig. 4. The map of environmentally sensitive areas to degradation for the rural area of the municipality Čukarica.

Table 6
Class distribution of environmentally sensitive areas to degradation in the rural part of the municipality Čukarica.

Class	Sub - class	Score range	Total area (km^2)	Total area (%)
Non affected	N	< 1.17	9.04	9.58
Potential	P	1.17–1.22	8.00	8.47
Fragile	F1	1.23–1.26	7.82	8.28
	F2	1.27–1.32	9.60	10.18
	F3	1.33–1.37	3.67	3.89
Critical	C1	1.38–1.41	9.13	9.68
	C2	1.42–1.53	24.78	26.26
	C3	> 1.53	5.29	5.60
Mask areas			17.05	18.06

Table 7
Correlation matrix.

LAYERS	SQI	CQI	VQI	MQI	ESAI
SQI	1	0.00	− 0.07	0.13	0.13
CQI	0.00	1	0.02	0.03	0.32
VQI	− 0.07	0.02	1	0.50	0.87
MQI	0.13	0.03	0.50	1	0.75
ESAI	0.13	0.32	0.87	0.75	1

first identifying the site's susceptibility to degradation and by applying appropriate measures.

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